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During this 18 month short term initiative grant we have developed a new state of the art ERP laboratory based on Macintosh computers and labview software that can record up to 64 channels of EEG input. In this report we describe this system, its potential and include a manual for its operation. In addition, we have completed two experiments that show a distinction between words and consonant strings that is maximal for occipital lobe electrodes and that occurs within the first 250 millisec after input. In addition, words also differ from consonant strings in the lateral distribution of electrical activity over posterior temporal leads within the first 200 millisec following input. These two results conform to findings using PET suggesting an area sensitive to orthographic regularity in the left ventral occipital lobe (Snyder et al, 1989). In a third experiment, subjects attended to feature, letter or word information. There was clear evidence that search functions were different between the three types of material. We are in the process of determining if these differences conform to anatomical differences in electrical activity.

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Cognitive Electrophysiology Experiment System

This system was designed to acquire and analyze measures of human brain electrophysiology (ERP and EEG) during cognitive experiments. Commercial systems are available for analyzing EEG and ERP data, but these are not capable of acquiring sufficient channels (e.g., 64 or 128) for high resolution analysis of scalp topography. Furthermore, these systems are typically restricted to analytical procedures used in clinical settings, rather than the general mathematical methods required for advanced approaches to current density topography and source dipole modelling.

Workstation Platform

We built this system with several design constraints in mind. First, it is an advantage to have as many functions as possible in the same hardware. Our previous research included as many as 5 computer systems, with differing hardware, operating systems, and data representations, to handle the various tasks of experiment timing, stimulus presentation, EEG acquisition, signal analysis, graphic presentation, and statistical analysis. For an inexpensive, general purpose workstation with a large and active scientific and engineering software base we chose the Apple Mac II series.

Acquisition Hardware

An important design requirement is the ability to acquire up to 64 EEG channels at high (e.g., 512 s/sec) rates. We use National Instruments boards, including a 16-bit A/D converter with 8 channels digital I/O and D/A converter. An auxiliary multiplexer allows up to 64 EEG channels to be accessed at one time. An auxiliary NuBus board provides DMA (Direct Memory Access) service for the A/D converter, so that EEG data can be acquired direct to memory with no processor intervention. This frees the Mac up for controlling the experiment while EEG data are acquired. Multiple hardware clocks on the A/D and DMA boards provide for several modes of accurate timing of experimental events. The 16-bit A/D converter provides 64 K amplitude resolution, allowing a wide dynamic range for near-DC recordings while guaranteeing adequate resolution of even small experimental effects.

EEG Amplifiers

Although 64-channel arrays can be formed from commercial amplifiers, these are quite expensive, e.g., $500/channel. Furthermore, increasing the number of channels introduces substantial sampling slew to the multiplexed sampling operation, i.e., the elapsed time from starting to sample the first channel to ending sampling of the last channel. We worked with electrical engineers to design an amplifier system that would include on-board sample-and-hold circuits, allowing voltage at all channels to be sampled at once and held, such that multiplexed A/D conversion could proceed sequentially with no sampling slew. Currently, the multichannel amps are configured 4 per PC board, with 8 boards in a box. Two boxes can be linked on the common multiplexer, providing 64 channels. With two multiplexers, 128 channels could be achieved, enough to avoid the spatial aliasing of scalp electrical fields recently described by Gevins and associates.

To insure subject safety and low noise, the amplifiers are built around Analog Devices isolation amplifiers, which isolate both the signal and power supply to the first amplification stage. Simple RC networks plug in on 8-pin dip switches to provide inexpensive hipass and lopass filters (initially set at 0.1 and 50 Hz). A sharp notch filter at 60 Hz eliminates noise from line current. With very high input impedance (> 100 meg Ohm), the amplifiers have excellent common mode rejection. This is important because it allows electrode impedances to be higher, and more unbalanced, than is typical for traditional EEG recording methods.

In the present configuration, testing electrode impedances is done with an external device. Similarly, calibration of zero and gain values of the amplifiers is accomplished by plugging an external device into the amplifier inputs. A second generation of amplifier boards now under construction includes integral calibration and impedance testing under software control, such that impedances can be checked easily at multiple times during the experiment, and bad electrode contacts attended when necessary through examining a color-coded map of the 32 or 64 channel montage on the Mac screen.

Geodesic Electrode Net

With this new amplifier design, we are experimenting with new technologies for scalp electrodes. We have had a 32-channel Electrocap constructed, which can allow topographic studies with this conventional electrode technique. However, closer electrode spacing may be difficult because of paste leak between adjacent electrodes (which cannot be seen under the cap). Another problem with this conventional method is the scraping of the scalp to achieve low impedances. Not only is this uncomfortable with many channels, it requires cap sterilization to avoid infection risk.

Our design involves chlorided silver electrodes in a narrow plastic tube 3.5 cm long. The tube is filled with a sponge wetted in a saline/detergent solution. The saline provides electrolytic contact, while the detergent dissolves the scalp sebum and allows the saline to form a conducting contact with the scalp. -We fit the electrode tubes with collars at 1 and 2 cm from the tip. The collars are threaded with elastic thread into a net of electrodes (Figure 1).

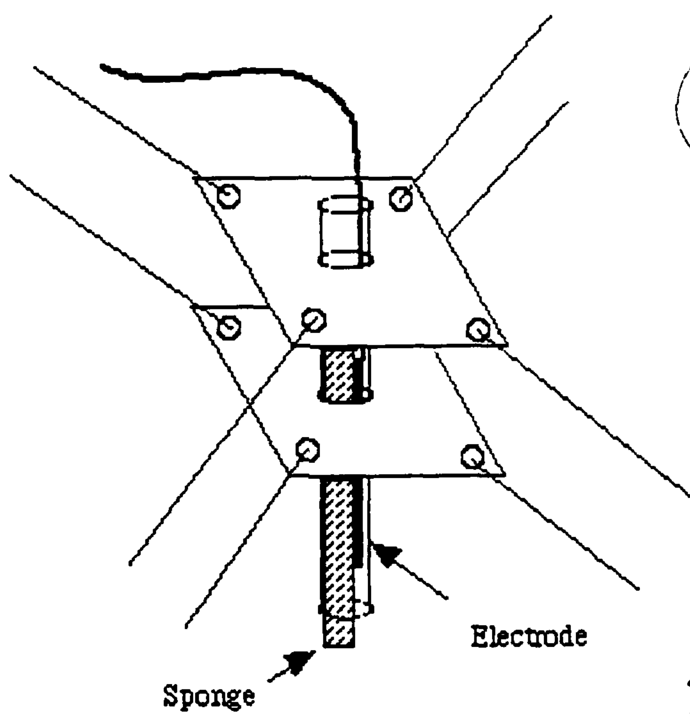


Figure 1. Design of saline electrode for the present net prototype.

The geometry of this net forms half of an icosohedron, the platonic polygon describing a sphere. Dividing each triangle of the icosohedron in regular intervals provides an equal spacing on the sphere surface, as in a geodesic dome (Figure 2). This spacing yields 61 electrode positions. With a 64-channel amplifier set, this leaves 3 channels for recording the electro-occulogram and an a left mastoid channel (the right mastoid is the common reference for all channels).

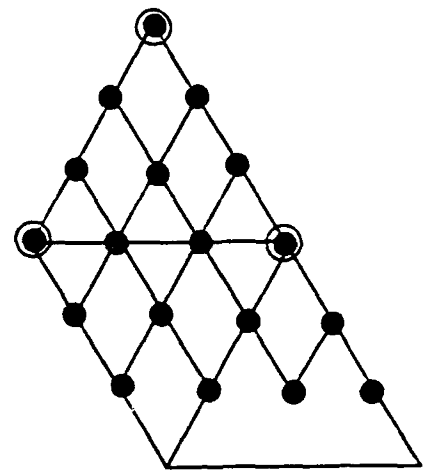


Figure 2. One of 5 repeating patterns of the partitioned partial icosohedron forming the geodesic net of saline electrodes.

Our initial tests with the first prototype of this design, populated with 32 electrodes, show that the net is appreciably more comfortable than the electrocap. It is fairly easy to seat the electrode tips through the hair, achieving impedances in the 10-30 K Ohms range (versus 3 K Ohms for conventional low impedance designs) in about 5 minutes of application time. The net yields high amplitude EEG, with similar artifact susceptibility as conventional electrode methods, except for a greater sensitivity to artifacts caused by head movements. Testing with new 64-channel protctype will begin soon. If adequate funding were available, a 128-channel system could be implemented within the next year.

EGIS: Experiment Control and EEG Acquisition Software

The A/D, DMA, and digital I/O board are handled by LabDriver routines provided by National Instruments. We have integrated these into a Pascal software shell that includes several functions required for many cognitive electrophysiology experiments. One common function is access to a standard file structure, with descriptive headers for the experimental session, and for each "task" or analytic unit of data collection (i.e., a cell in an ANOVA design). Another is calibration of zero and gain of the amplifiers prior to the experimental run, and insertion of calibration data into the session header.

The most complex function provided by EGIS is display of the EEG or ERP (i.e., stimulus-synchronized) data using the flexible window modes of the Macintosh. Figure 3 shows a 14-channel ERP montage plus EOG channel. Two windows of 8 channels each show the general pattern of the ERP for this subject, while a zoom window has been created to examine the left parietal (P3) channel more closely. A flexible pattern of window definitions can be created for such tasks as monitoring the EEG during the experiment, or inspecting averaged and grand-averaged ERPs during data analysis. An important use of EGIS is examining the data for noncephalic artifacts (eye movements, EMG, swallowing, etc) prior to averaging or statistical analysis. The text window at the bottom of Figure 3 shows the artifact flags and the descriptive information for the ERP data being examined for this subject.

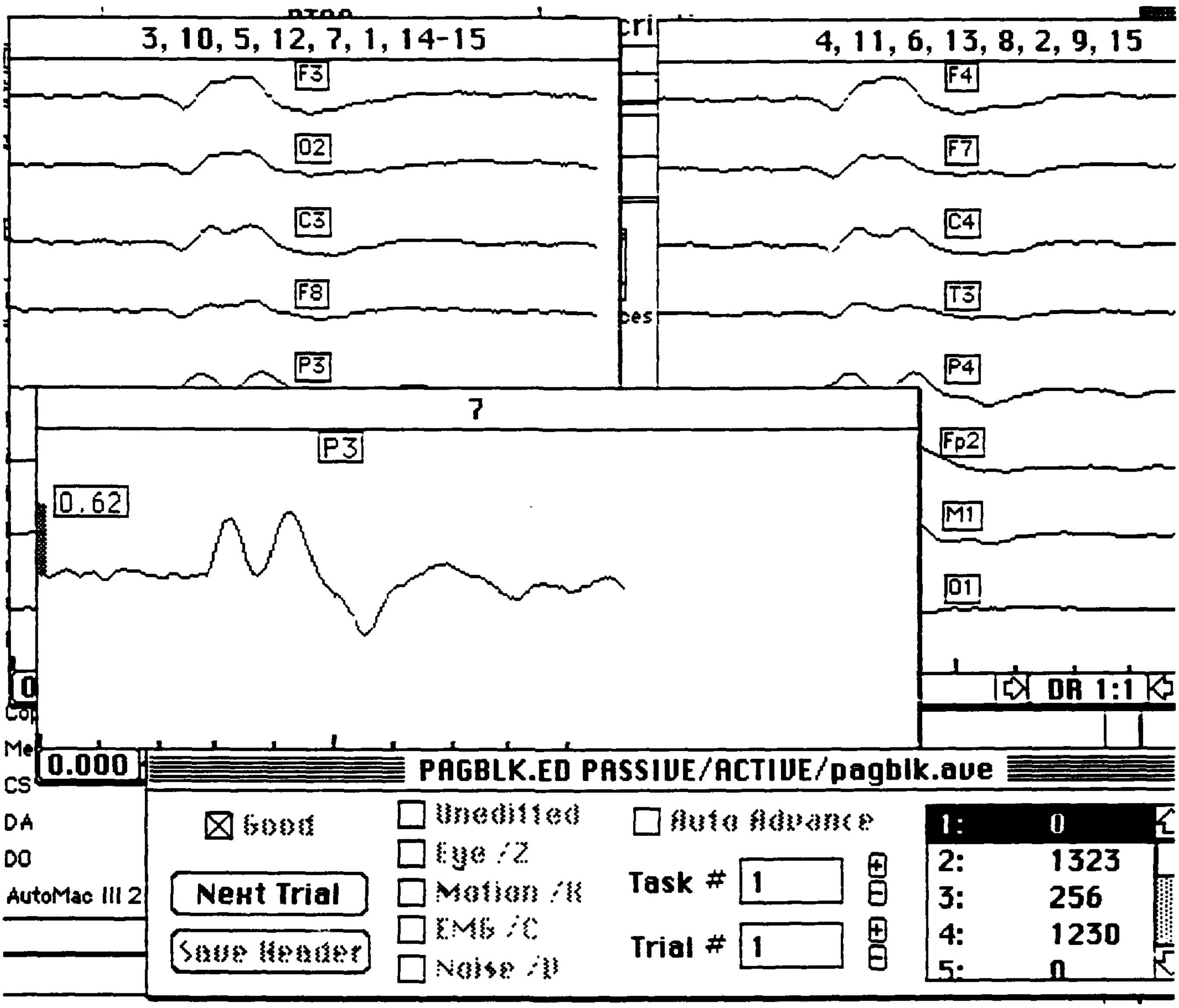


Figure 3. Example waveform display windows from EGIS.

Other functions in EGIS allow browsing the header information for the currently accessed file, and acquiring data in "oscilloscope mode" direct from the A/D converters. Given the functionality of the EGIS shell, constructing a cognitive electrophysiology experiment requires writing a Pascal program that determines the experiment structure and timing, presents the stimuli, etc. This program is then inserted within the EGIS shell. Part 1 of the EGIS user's manual (introduction and overview of functions) is provided as an appendix. Part 2, currently being written, will describe how to write and implement an experiment program.

LabView Signal Analysis Modules

Although precise timing of experimental events and maximal use of display parameters requires the control over the machine that can only be achieved with a conventional programming language, there is a new generation of computer software that is beginning to allow users powerful programming capacities without the instruction-level specification required in conventional languages. A novel approach has been taken by National Instruments with their LabView system. This system provides modules that perform many arithmetic and signal analysis functions, such as array inversion or Fourier transforms. In addition, users can construct custom modules, termed "virtual instruments", which are then integrated into more complex modules. The organization of the icons representing virtual instruments is achieved by a block diagram, in which data flow is achieved by "wires" connecting icon modules, and structures such as For loops are also implemented in iconic form. An example of a LabView block diagram is given in Figure 4.

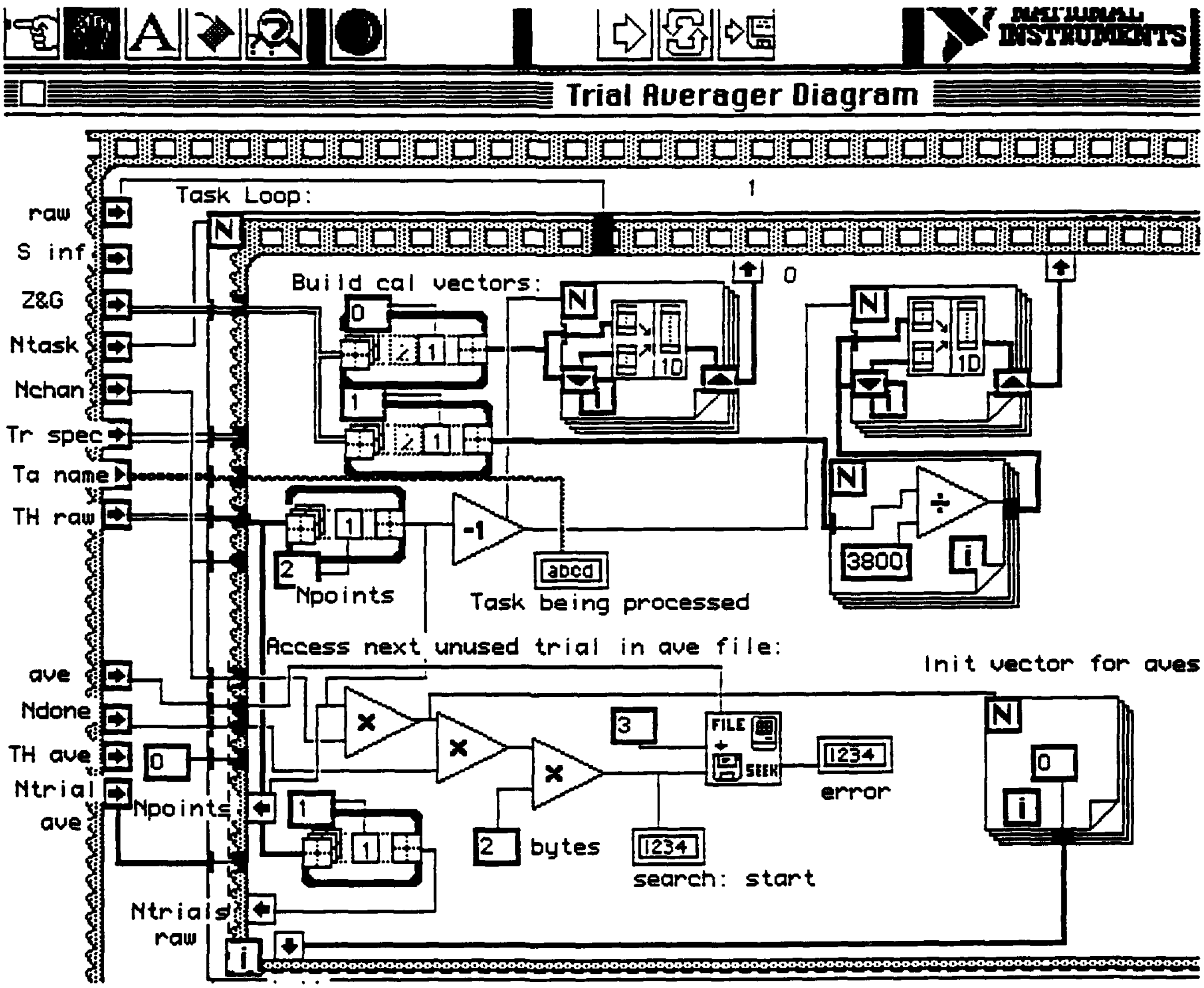


Figure 4. Example of LabView Block Diagram. From Trial Averager.

We have constructed a small library of virtual instruments (VIs) for analysis and display of ERP data. Several VIs are used to access the header structure we have standardized for our file structure. When these are implemented, all the data from the experimental session, including performance and descriptive as well as electrophysiological data, is available in data "wires" for LabView display and analysis. VIs have been written for averaging the ERP data across trials for each subject, with a "trial filter" VI that can be customized for each averaging run to eliminate trials according to various criteria (usually artifacts or inappropriate performance data). A grand averager computes grand averages across subjects. Several display VIs access and display the ERP data in a form suitable for import into a paint program (such as shown in Figure 5).

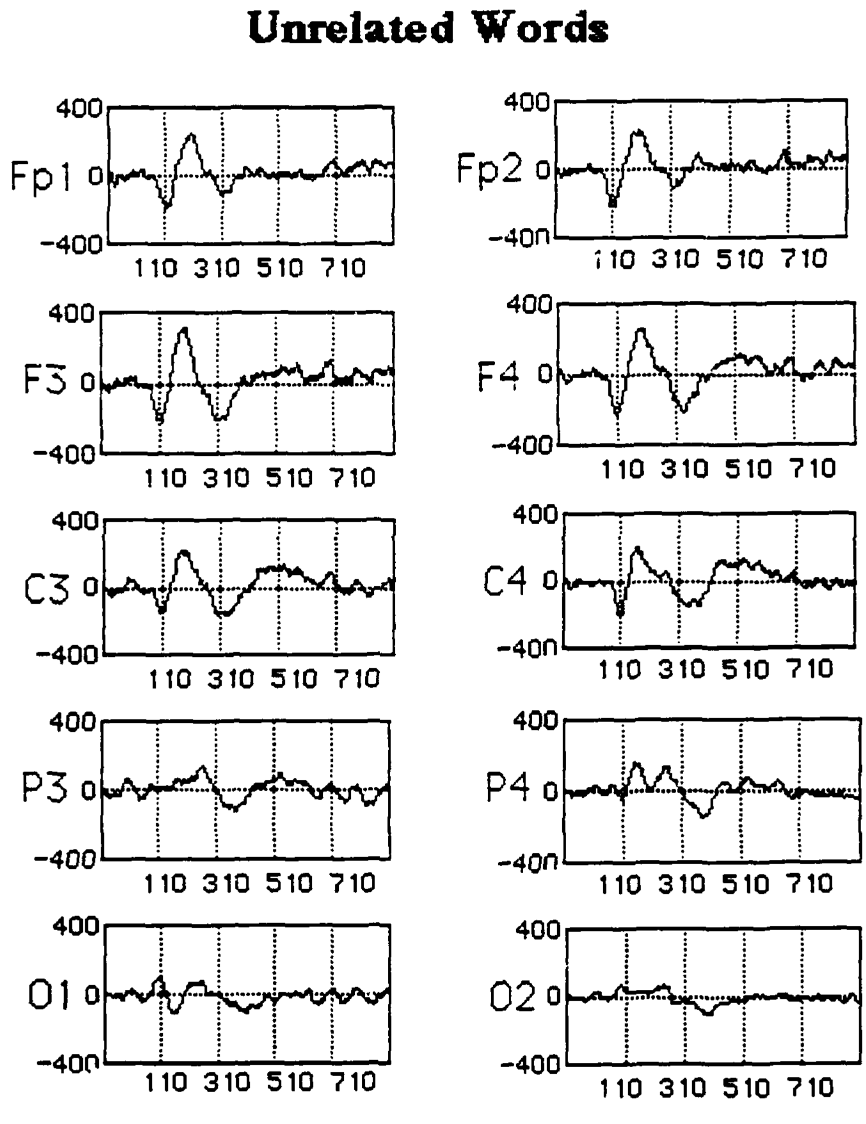


Figure 5. Part of a LabView display of ERP data (from an N400 experiment).

Another set of VIs has been constructed to compute the Hjorth approximation to the radial current density from ERP data. An important problem with conventional ERP methods is that the voltage recording is dependent on the site of the reference electrode. Methods of computing current density characterize the gradients in the voltage map; where voltage has the greatest gradient is where radial current density -- current flow perpendicular to the scalp surface -- will be the greatest. Although computing current density accurately requires a large number of electrodes to characterize a precise voltage surface, Hjorth [Hjorth, 1982 #1003], has presented an approximation to current density, in which the value at each electrode site is computed as the gradient directed toward that site from all other electrode locations. This method yields what is essentially a distance-weighted average reference. It can also be described as the first derivative of the voltage surface. It is clear that reference-free derivations are essential to relate scalp electrical data to anatomical locations, and measures of current density are rapidly becoming the standard for topographic studies.

Spline-Surface Laplacian Method of Computing Current Density

If enough electrodes are available to generate an accurate characterization of the voltage surface at the scalp, then current density can be computed directly as the Laplacian or second derivative of this surface [Perrin, 1987 #18]. The problem with this technique is that in addition to needing many channels, it requires a smooth interpolation of the voltage surface. Any discontinuities of this surface, such as with linear interpolation, become exaggerated by the second derivative function.

We have developed an interpolation program, named Interpolator, that computes a cubic spline interpolation on an array of irregularly spaced EEG electrodes. Part of the control panel of Interpolator is shown in Figure 6.

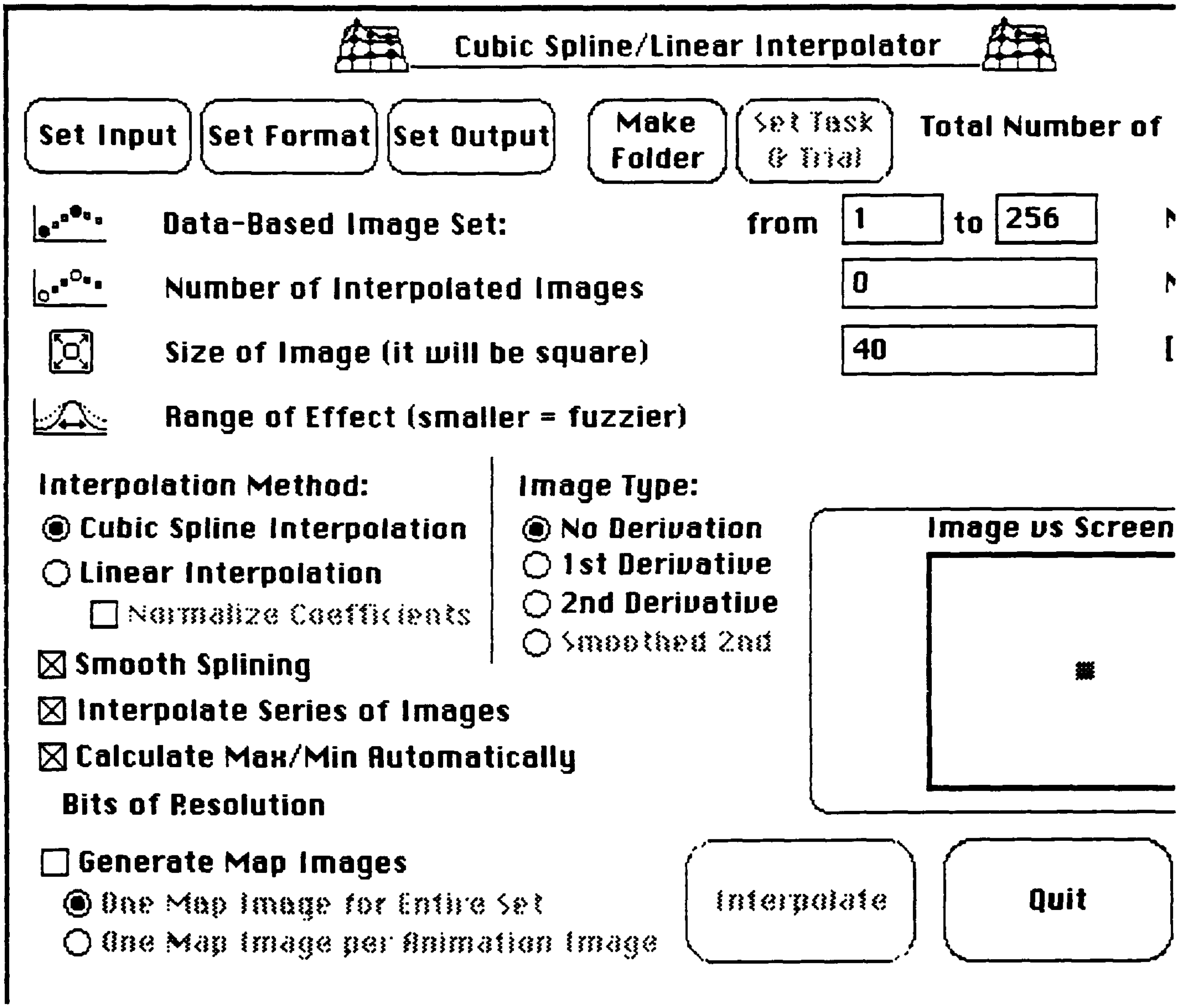


Figure 6. Control Panel of Interpolator.

The spline surface can then be used to create the Laplacian or second derivative. By computing the voltage or current density surface at each sampling interval (e.g., 256 s/sec), an animation of the topography of the ERP can be created. By showing the rapid variation of electrical activity over time, the ERP may show features of brain function that cannot be seen with other neural imaging methods such as Xenon Cerebral Blood Flow or Positron Emission Tomography.

Once the interpolated images have been generated, they can be imaged with image processing software. We import the animations into NCSA Image, one of the programs in the software suite for the Macintosh written at the National Center for Supercomputing Applications at the University of Illinois, Champaign-Urbana. This software brings high quality workstation functionality to the inexpensive Mac platform. NCSA supports the software very well, and provides excellent consultation on its use. Although the color displays and of course animations cannot be shown in this document, the contouring option from the raster image of one frame of an ERP animation is shown in Figure 7.

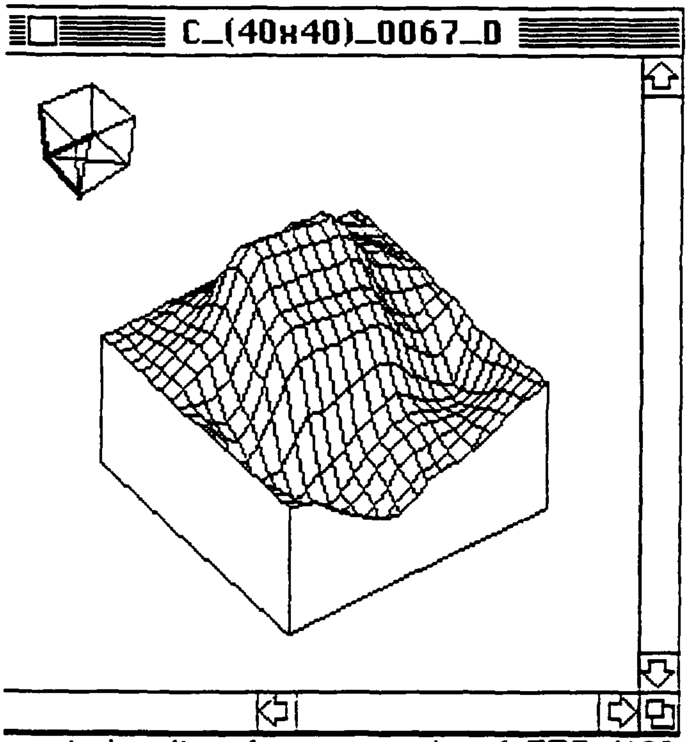


Figure 7. Hjorth current density of one sample of ERP (180 ms poststimulus). The top left of the cube is the forehead; the lower right represents the back of the head. Higher points on the surface represent current sources; low points represent current sinks.

Nonparametric Waveform Significance Test

When comparing two ERP waveforms on an exploratory basis, such as between two conditions of a cognitive experiment, it can be useful to have an index of the extent to which observed differences in waveforms are statistically significant given the sample size and waveform variances in the present sample. We have created a program, DiffTest, that computes the Wilcoxin sign rank test for to compare every sampling point between two ERP waveforms. When more than 5 samples in a row are significantly different at the designated significance level, a bar is drawn at the bottom of the plot. Although hypotheses are clearly important to guide experimental design and statistical analysis, this exploratory analysis tool is proving very useful for EDA -- the Exploratory Data Analysis advocated by Tukey -- a rapid overview of significant effects that might otherwise be missed in a strict hypothesis testing approach. The new leads can be examined for replication in subsequent experiments. An example of the graphic output of DiffTest is shown in Figure 8.

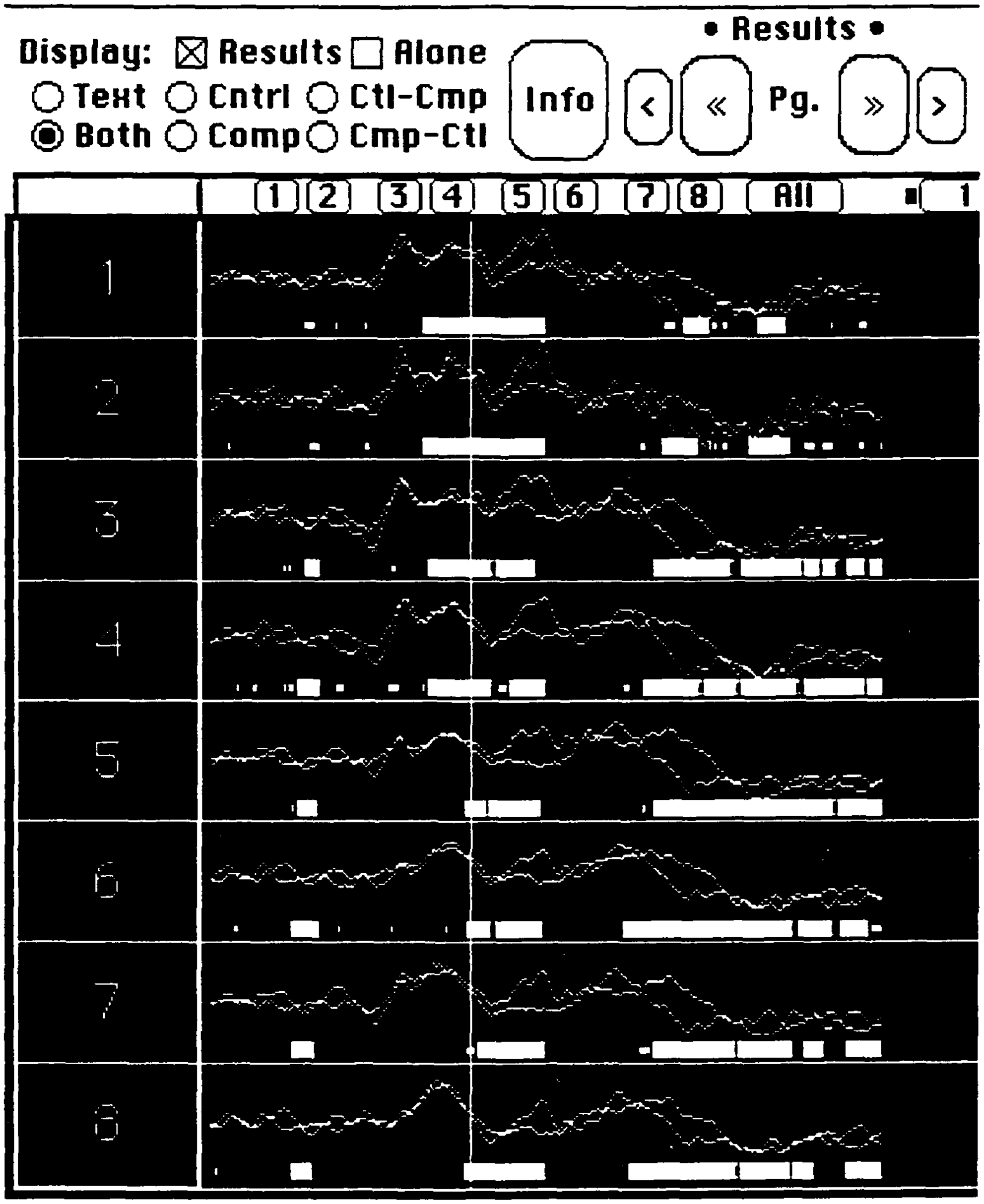


Figure 8. Graphic output of DiffTest showing comparison between 2 ERP waveforms (original in color). Areas designated by bars at the bottom are statistically significant for this sample at p < .05.

EXPERIMENTS

Introduction

Experiments were designed to allow characterization of differences in scalp electrical activity associated with the word recognition process. Specifically, we intended to test a model which suggests separate processes for recognition of visual features, letters, and words. (McClelland & Rumelhart, 1981, 1982, 1986). Although we have not attempted for specific localization of these processes in the brain with our current event related potential (ERP) methods, there is evidence from PET that there are such differences (Snyder, Petersen, Fox, Raichle, 1989). The application of the ERP to this question is in determining the specific time course of these processes while retaining some general location information.

Method

Three classes of stimuli were designed to differentially activate the three processes suggested by the model. Visual features similar to those found in words were incorporated in the false font stimuli. Letters with no meaning or phonological equivalent were presented in the consonant string stimuli. Finally, high frequency words were used . Each stimulus type was presented in strings of four or six characters as specified in the description of the individual experiments.

The word stimuli were chosen to be high in frequency in order to have the greatest chance of activating a highly practiced or automatic word recognition system. 100 six-character high frequency words were selected. An equal number of four-character words were chosen that matched the six letter words as closely as possible in frequency. Each of these sets were then divided in half in a way which matched the relative frequencies of words in the subsets for counterbalancing purposes.

Consonant string stimuli were designed to preserve as much as possible, the letter frequencies in the word stimulus set. This was done by assigning to each letter in the word set, another letter which was as close as possible in frequency, and then substituting directly to generate the consonant string stimuli. The vowels in the words were assigned high-frequency consonants which also were mapped to other consonants, so the transformation is not one to one.

False font stimuli were generated by assigning to each letter of the alphabet a character from the Hebrew alphabet or another character visually similar to letters (Gibson, Shurcliff, Yonas, 1970). The Hebrew alphabet was chosen as a source of visual forms which convey a similar sort of information as letters do in English, but which are unfamiliar to subjects screened for knowledge of Hebrew. A one to one mapping was constructed, so that each letter was replaced consistently by a unique substitute character. The original word stimuli were then used to generate the False font items by using the replacement characters instead of their corresponding letters.

General Procedure

The subjects for these experiments were recruited via public posting at the University of Oregon Department of Psychology. They were paid for their participation. Right handed native speakers of English, with no knowledge of Hebrew and no reported reading deficits, were eligible. Ages ranged from 18 to 43, with approximately equal numbers of women and men participating.

These stimuli were presented under conditions described below for each experiment. Some aspects remained constant across experiments. In all cases, the four or six character stimuli were presented in the center of a computer monitor screen at a location previously occupied by a fixation mark. The involved computer also controlled the acquisition of scalp electrical signals time locked to stimulus presentation.

Electrical activity at fourteen scalp locations was recorded using the Electrocap system. Electrode locations in the International 10-20 system were F3, F4, F7, F8, C3, C4, P3, P4, T3, T4, T5, T6, O1 and O2. Eye movements were also recorded. The amplifiers used had a 0.5 Hz low-frequency roll-off, and a low-pass filter at 50 Hz.

Signals were digitized at rate of 256 samples per second and stored to disk for later analysis.

The collected data was later manually edited for artifacts of eye movements, muscle activity, movement or electrical noise. About 10% of trials were eliminated using this conservative procedure. Signals not eliminated were averaged to yield the ERPs.

Experiment 1

Procedure

Experiment 1 involved two cognitive tasks as well as passive stimulus presentation. There were four blocks of 200 trials involving these task conditions. Each block included 50 four-letter words, 50 six-letter words, and 25 each of four and six character consonant strings and false font strings. These stimuli were taken from the two subsets described above, presented in counterbalanced order. Subjects did not see the same stimulus set on subsequent blocks of trials.

In the first block, each subject saw stimuli without any task instructions. They used a key press to indicate their readiness for the subsequent stimulus, but otherwise they passively observed the monitor screen. In the next block, Half the subjects then performed a lexical decision task on 200 additional trials, indicating with a key press whether a stimulus was a familiar word (50%) or not. The other half of the subjects performed an "estimate length" task, indicating with a key press whether the overall size of the stimulus, regardless of character type or lexical content, was short (50%) or long. Performance on these tasks was essentially 100%, but the rare errors were *eliminated from ERP averaging. Each subject group then performed the other* cognitive task, and finished with an additional passive observation block.

Results

After editing and signal averaging, the ERP data from occipital and posterior temporal electrode locations were analyzed for differences using repeated measures ANOVA. Reported probabilities are corrected using Greenhouse-Geiser Epsilon to adjust degrees of freedom. Mean signal values were extracted over intervals centered on the latencies of component peaks in the grand average ERP. Intervals analyzed included P1 (75-130 msec), N1 (130-180 msec) and P2 (180-25- msec occipital, 220-320 msec posterior temporal). The effects of the false font stimuli will be further addressed in the discussion of the subsequent experiment. These results will be confined to the measures of word and consonant string responses only.

Occipital Electrode

For occipital locations, there was no effect of stimulus type in the earliest interval. In the 130 to 180 msec period, there was a main effect of laterality, with the left side having a more negative voltage overall, $F(1, 14) = 4.608$, $p<.05$). (See Figure 9)

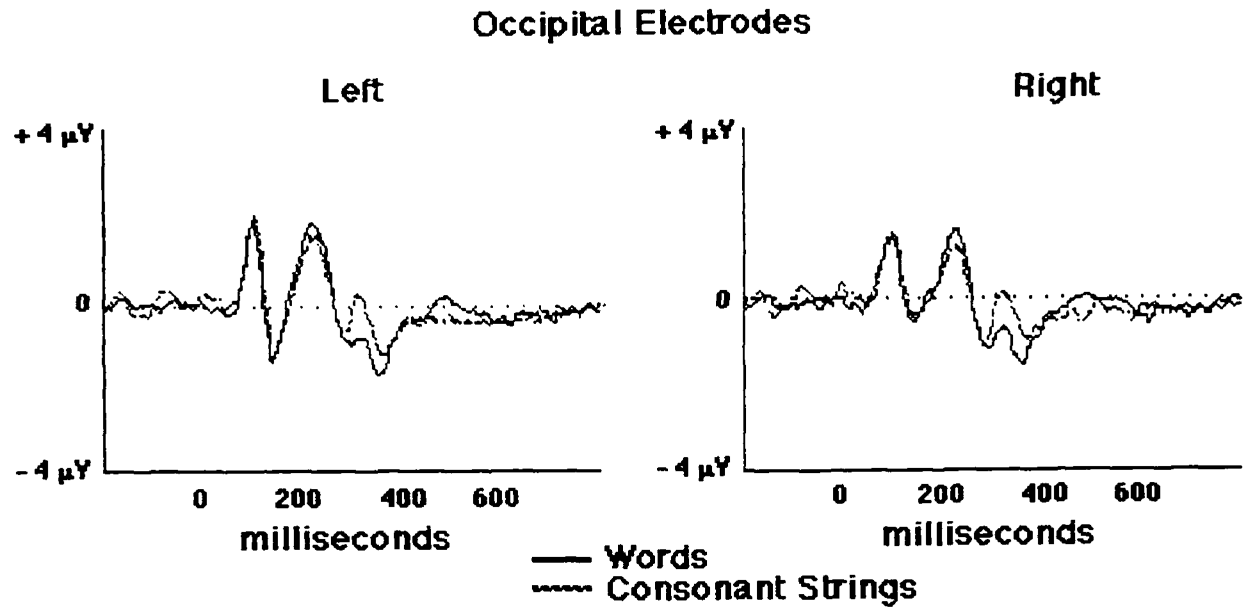


Figure 9. Experiment 1, Occipital electrode EPP's for words and consonant strings.

An interaction of subject's cognitive task with stimulus type, was also significant, F[3, 42) = 3.613, p<.028. Words resulted in more negative signals than consonant strings only in the context of the lexical decision task. In the interval of 180 to 250 msecs, occipital mean voltage showed main effects for several experimental variables. There is a main effect of laterality, with the left side showing a more positive mean than the right, F(1, 15) = 5.29, p<.036. There was an effect for stimulus length, with six character stimuli showing more positive voltage than four character stimuli, F(1, 15) = 6.417, p<.023. Also, there is an effect of stimulus type, with words resulting in a more positive mean voltage than consonant strings, F(1, 15) = 5.309, p<.036. There is a significant interaction of stimulus length by laterality, F(1, 15) = 11.206, p<.005. Six character stimuli are more positive than four character stimuli at both electrodes, and this effect is slightly larger on the left.

Posterior Temporal Electrodes

In the 75-130 msec interval, there is an effect of laterality, with the right posterior temporal site being more positive on average than the left. However, a complex interaction of all four experimental variables is found at this interval. Wide differences in variance across the various levels suggests this result is spurious.

In the 130 - 180 msec interval, there is an interaction of stimulus type with laterality. The word stimuli are more asymmetric than consonant strings. For words there is a a difference in means of approximately 0.31 µvolts, left more negative. Consonant strings show a difference of less than 0.10 µvolts, with the left side again more negative (See Figure 10).

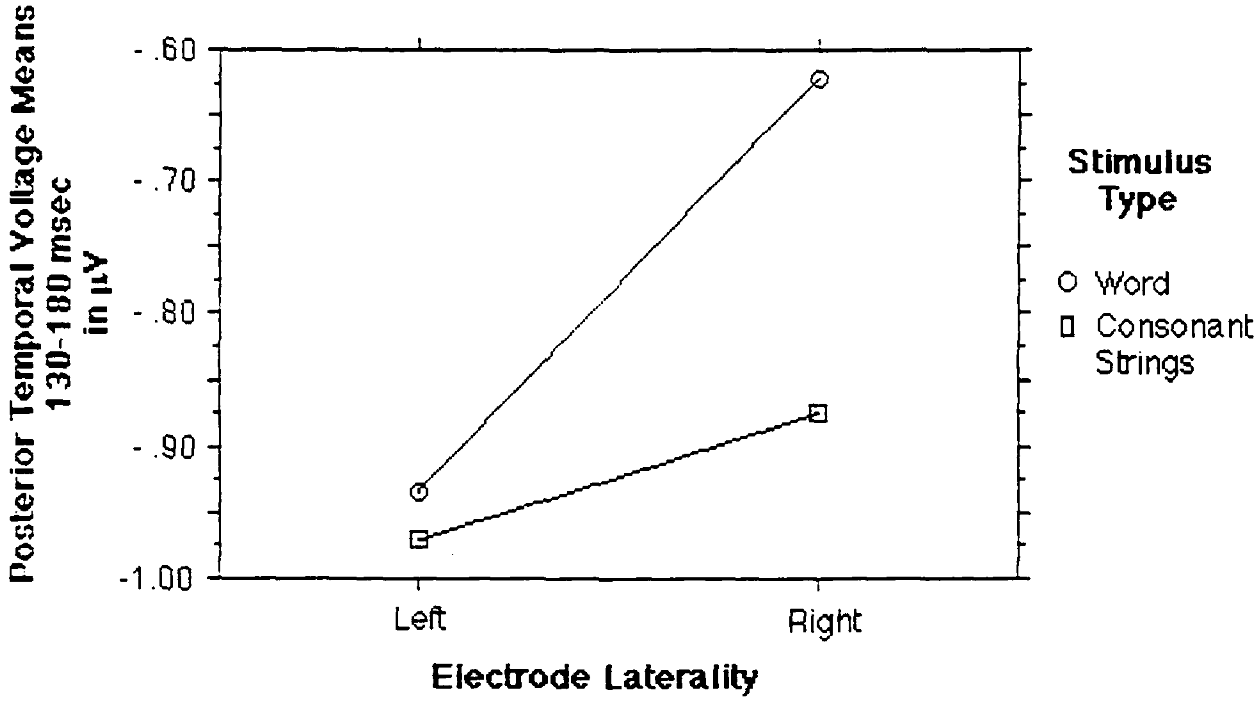


Figure 10. Experiment 1, Posterior Temporal locations. Interaction of stimulus type with laterality.

Experiment 2

Procedure

There were results in Experiment 1 that indicated a difference between words and false font stimuli in the period 75-130 msec post-stimulus at occipital sites. ERPs of this latency are extremely sensitive to the effects of exogenous stimulus properties, such as luminance. The Experiment 2 was intended to replicate aspects of the previous study while eliminating any overall luminance differences. This was done by equating the pixel activation count for letters and their corresponding characters in the false font stimuli. No consonant string stimuli were used in this study.

Block organization and cognitive tasks remained the same as in the PA study, with the exception of the number of trials. In PA2, there were 35 trials of four letter words, 35 six-letter words, 35 four-character false font stimuli, and 35 six-character false font stimuli, for a total of 140 trials per block. The ratio of yes to no responses remained 50% for both the lexical decision and estimate length tasks.

Results

Occipital Electrodes

As suspected, the equalization of pixel count across stimulus type eliminated any effects on occipital voltage mean in the 75 to 130 msec latency range. In the 130 to 180 msec period, there is a significant interaction of stimulus type with electrode laterality, $F(1, 15) = 7.995$, $p<.013$. The non-word stimuli show greater left-sided negativity than words. In this case, however, the non-word stimuli are false font, and the location of the asymmetry is occipital rather than posterior temporal (See Figure 11).

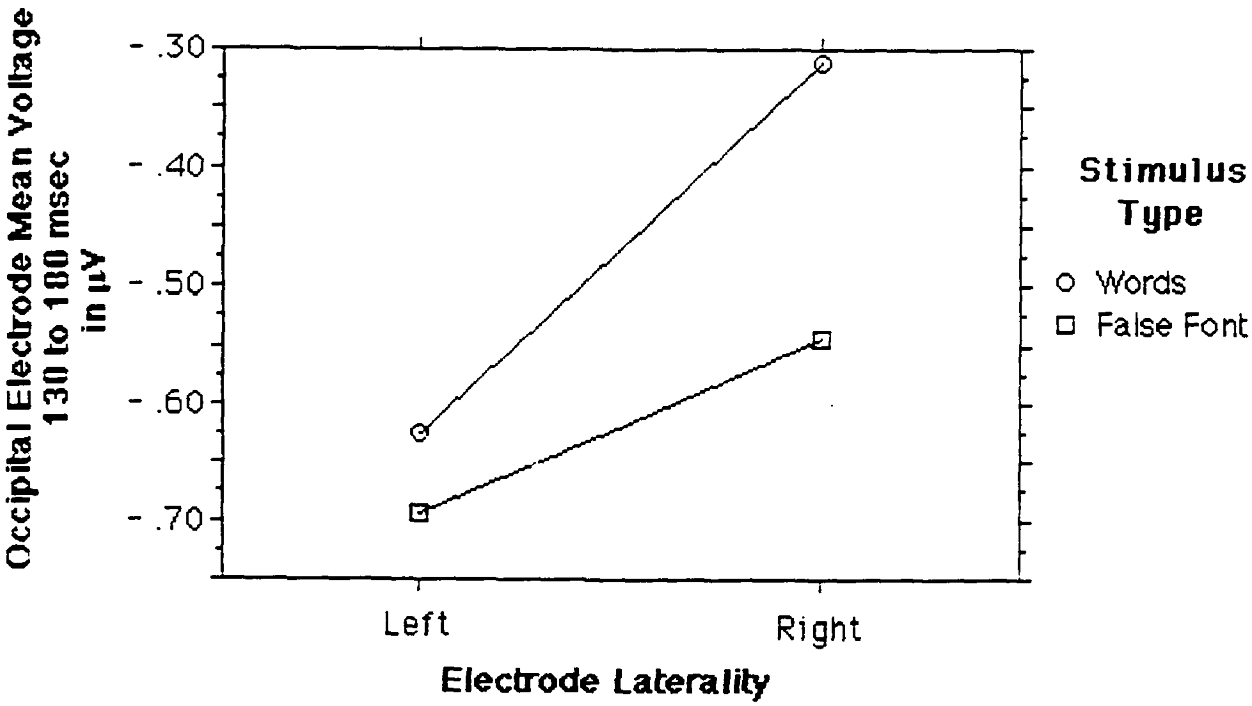


Figure 11. Experiment 2. Occipital locations, interaction of stimulus type with laterality.

In the period 180-250 msec, there is a main effect for stimulus type, with false font stimuli more positive than words, $F(1, 15) = 8.03$, $p<.013$. Also, a main effect for stimulus length is seen, with six character stimuli more positive than four character, $F(1, 15) = 8.43$ $p<.011$.

Posterior Temporal Electrodes

At posterior temporal locations, in the 75-130 msec interval, there is an interaction of stimulus length and laterality. On the right, four and six character stimuli are very similar, while on the left, six character stimuli are more positive than four character, $F(1, 15) = 7.461$, $p<.016$. Another multi-factor interaction is seen here, with subject task, stimulus length and laterality as factors. In the N1 epoch, here defined as 130-200 msec due to changes in latency of the N1 peak in the grand average, there is again a stimulus type interaction with laterality, $F(1,15) = 6.237$, $p<.025$. In this case, the response to false font stimuli is more negative on the right side, while the response to words is more negative on the left. Finally, in the P2 interval, 200-300 msec, there is an effect for stimulus type, $F(1, 15) = 65.08$, $p<.0001$. False font stimuli are overall much more positive than word stimuli.

Discussion

The results of Experiment 1 and 2 support the PET finding (Snyder, et. al., 1989) that words and consonant strings differ in their effects in the occipital cortex. Moreover, according to Experiment 1, this difference occurs between 180 and 250 millisec after input. The difference found in these posterior electrodes is earlier than any other difference we observed thus it appears unlikely it is fed back from any higher level. It appears likely that the distinction between words and consonant strings is made during the input phase.

Electrical amplitude for both words and consonant strings is larger over the left than over the right cerebral hemisphere. There is some laterality difference between the two types of strings when posterior temporal electrodes are examined (See figure 10). The word stimuli show a larger right to left electrical difference than the nonwords in the 130-180 millisec time period. We expected the word consonant string difference to be larger over the left hemisphere in accord with the PET finding of a left ventral occipital blood flow difference. However, our 16 electrode array is not sufficient for us to say much about the generators of these effects. More details will have to await use of our new 32-64 channel system.

Experiment 3

Introduction

Word reading depends on complex perceptual and cognitive processing that requires a great deal of practice before successful performance is possible. The fact that reading becomes an easy, effortless task in the skilled reader suggests that required processes may become supported by the functional organization of neural systems. As noted previously, a model of word reading that has guided our work is described by McClelland and Rumelhart (1981, 1984, 1986). Their model posits perceptual processing of features, or discrete parts of letters, which enables computation of letters based on these features, and letters are then processed into words.

Recently (Corbetta et al, 1990) it has been shown that attention to aspects of visual stimuli can enhance blood flow in prestriate areas that code color, form or velocity information. If this is also translated into enhanced electrical activity, we can use attention to alter components of the event relate potential.

This line of thinking led us to design tasks that seek to target different components of word processing. By measuring response times in tasks that rely most heavily on different levels of representation, we sought to provide evidence relevant to possible processing levels. At the neurosystem level, the same set of tasks allows psychophysiological investigation of scalp-recorded evoked potentials that could shed further light on the time course (and perhaps neuroanatomical locus) of underlying processes.

Method

All 24 subjects were volunteer adult community members paid $5 per hour. All were right-handed, had normal or corrected-to-normal vision, and did not have reading disabilities. All stimuli were strings of four or six letters which occurred with equal frequency (50% each). All letters were displayed in upper case 25-point

Helvetica typeface, except as noted below. Each stimulus was either a word of moderate-to-high frequency (50%), or a non-word consonant string (50%). Consonant strings matched the word stimuli with respect to letter frequency and letter position. Each stimulus contained either a single letter containing a specially thickened segment (50%), or no such letter (50%). All 26 upper case letters were presented with a thickened segment at least once in the stimulus set. Each stimulus contained either a single lower case letter (50%), or no lower case letter (50%). Lower case letters that are the same shape as upper case were not used, thus yielding a set of 15 possible lower case letters. Small lower case letters were scaled to match the vertical extent shared by all other (upper case) letters in the stimulus string.

Position in the stimulus string of both thickened segment and lower case letters was equally distributed in both four and six letter stimuli. The frequency with which particular letters of the alphabet were presented in either lower case or with thickened segment was distributed as equally as possible. These stimulus parameters were all combined in equal partitions among two sets of 200 stimuli each. Thus some stimuli contained both lower case and thickened segment letters (25%), some contained neither lower case nor thickened segment letters (25%), and the rest contained either only a thickened segment letter (25%) or only a lower case letter (25%). Each stimulus was presented twice, in non-adjacent tasks, to comprise a total of 800 trials.

Equipment

Computerized control of stimulus presentation and response collection was provided by the Electrophysiology Graphical Imaging System (EGIS) together with software specifically generated for this experiment. This was the first experiment controlled by EGIS. Stimuli were presented on a black and white video screen comprising part of a Macintosh II platform. Digital input was achieved via a National Instruments NB-MIO16 board.

Procedure

Tasks

Reaction Time data were collected during performance of cognitive tasks designed to target different levels of cognition in word reading. Each task consisted of a sequence of 200 trials. Each trial presented one string of letters centrally replacing a fixation marker. The stimulus persisted until response by subject.

Each subject performed four tasks, the first being simple detection. This task was included for direct comparison of response time results with a planned ERP experiment using identical task organization except that no speeded responses are used. The remaining three tasks each maximized the subject's attention to one of the three levels specified in the model. In the feature task, the subject decided if the stimulus contained a letter with a thickened segment. The intent was to focus attention in the feature level by making presence of a thickened segment the task-relevant stimulus attribute. In the letter task, focused attention in the letter level by requiring the subject to decide if the stimulus contained a lower case letter. The Lexical Decision task focused attention in the word level by requiring discrimination between words and consonant strings. These latter three tasks were presented in tne six possible orders, one order per four subjects.

Order

Responses were generated by left and right thumb presses on a two-choice key pad. For consistent instruction across tasks, the key that the subject used in the simple detection task also designated target presence in the feature task and letter tasks, as well as the word response in the Lexical Decision task. This was the left key for half the subjects, right for the other half. The 24 subjects were counterbalanced among the conditions of stimulus set (2 levels), task order (6 levels) and response key (2 levels).

Subject Instruction

Each subject was given both verbal and visually presented instructions at the beginning of each task, and then practiced with twelve trials that provided error feedback while the experimenter was present. Feedback about response accuracy was not provided during the subsequent 200 experiment trials per task. Rest periods with length determined by the subject were provided between groups of 50 trials and between tasks. After the first two tasks each subject left the response collection booth for a brief walk to maintain alertness.

Results

EGIS

This test run of EGIS software was successful, though one bug was detected. Histograms of response times for individual subjects revealed a 7-msec cycle in the computer algorithm for response collection. This has subsequently been adjusted to a cycle of 1.5 msec.

Comparison Between Tasks

Performance was evaluated using both response time and error rate measures. These two generally showed quite similar results. Simple detection produced the fastest responses. Lexical Decision yielded responses that were slower than detection, but faster and more accurate than the two search tasks. The feature task produced faster responses and fewer errors than did letter search. This consistent grading of the four tasks on these two measures probably indicates an ordering with respect to task difficulty. Neither task order nor stimulus set produced measurable effects.

Search Function

Response times were longer for six-letter than for four-letter stimuli in the feature tasks and letter search tasks. This pattern was not found for Simple Detection and Lexical Decision. The ratio of slopes (from short stimuli to long stimuli) for correct "No" responses (target absent) over correct "Yes" responses (target present) measures the influence of increasing number of distractors on target detection. In feature search, an increase in stimulus length does not produce a marked impairment in response time for stimuli containing a thickened segment. In letter search, latency of correct responses to stimuli containing a lower case letter greatly depends on stimulus length. The six-letter stimuli yield much slower responses when the target is present in this task. This effect is much reduced for correct responses to target absence. The "No" slope for this task is nearly three times the "Yes" slope. (See Figure 12)

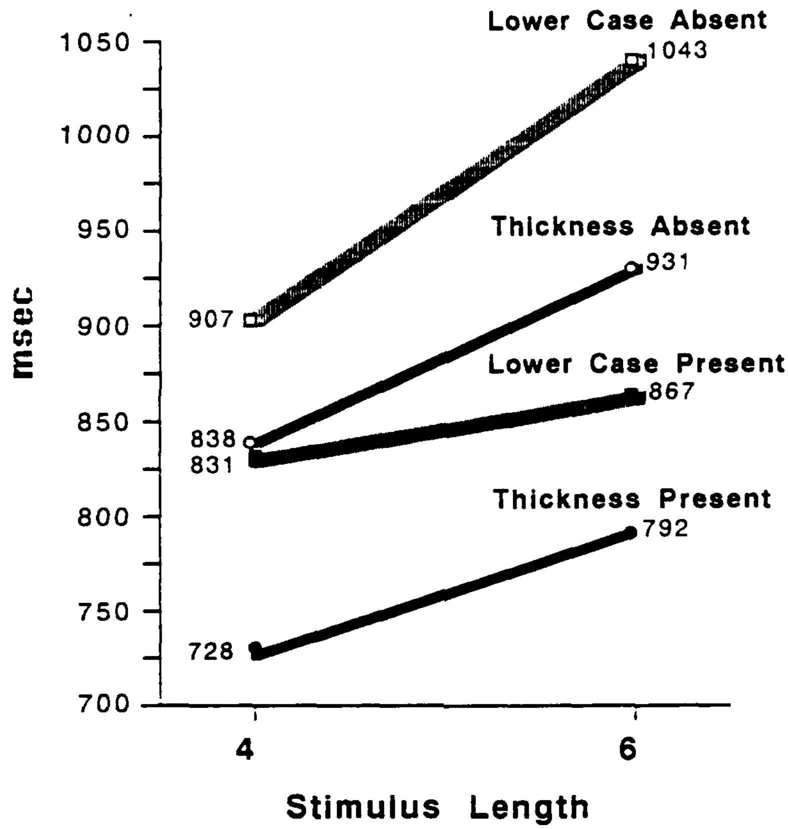


Figure 12 Response Times for correct responses in feature and letter tasks.

The effect of target letter position differs between feature and letter search tasks. In the feature task, response time is a U-shaped function with fastest responses to targets positioned in the center of the stimulus (see figure 13).

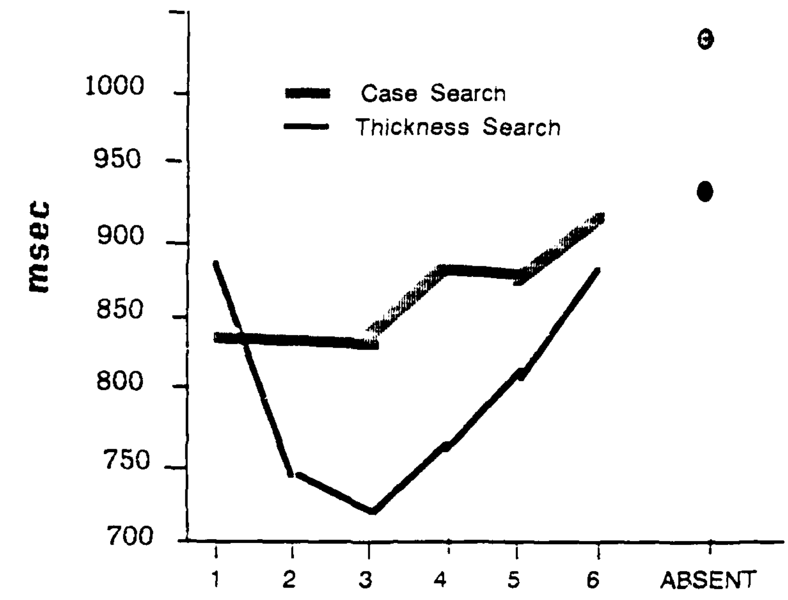


Figure 13 Response Times to 6-letter Stimuli as a function of target position.

In letter task, response time is more a linear function of target position. These data suggest use of parallel search procedures in feature task, while letter task may rely on more serial processing (Treisman, Gormican, 1988).

In feature task, words elicit faster responses than do consonant strings, unless the target is positioned near the center of the acuity function. Centrally presented targets produce faster responses in consonant strings than in words. In the letter task, there is little overall difference between words and non-words, but words yield slower responses to target presence, and faster responses to target absence than do consonant strings.

Discussion

A letter may be considered a bundle of features. A word seems to be an organized chunk of letters. The two kinds of search performed in the two search tasks differ from each other. The steep "no" slope in letter task indicates a more serious search not found in feature task. Attention seems heavily taxed in letter task, and not in feature task.

In feature task, targets seem to automatically pop-out. The fact that increase in stimulus length increases response time for "no" about as much as for "Yes" argues strongly for a more parallel search. The effect of target position in stimulus string provides converging evidence: since the U-shaped curve is probably based on acuity.

Three distinct findings in the two search tasks directly bear on the relation between features, letters and words; converging evidence is found in the effects of target presence, target position and lexicality. Effects of target presence distinguish feature task as more parallel, and letter task as more serial. Effects of target position corroborate the serial nature of letter task and has the acuity function in the feature task. Stimulus lexicality clearly dictates performance in a letter-level task, whereas lexicality produces only a subtle interaction in the feature-level task. These results fit the McClelland and Rumelhart model.

A visually presented word provides organizing structure to constituent letters and features. This organizing structure is not found for strings of consonants. Lexicality affects response time in a search task at the letter level more than in a search task at the feature level. The organizational structure of a word may hinder processing of component letters, compared to consonant strings, in tasks that elicit relatively quick responses, because of the lag due to inhibition of automatic grouping of letters into the word. The same organizational structure may also be responsible for enabling more efficient processing of search when no target is present, regardless of representation level (letter or feature), by providing well-defined search boundaries.

Current Studies

Our current studies are comparing the scalp distribution and putative generators during the tasks discussed above. Our goal is to determine the areas of electrical enhancement found as subjects attend to feature, letter and word levels. We felt it important to develop a system of 32-64 electrodes in order to carry out this research.

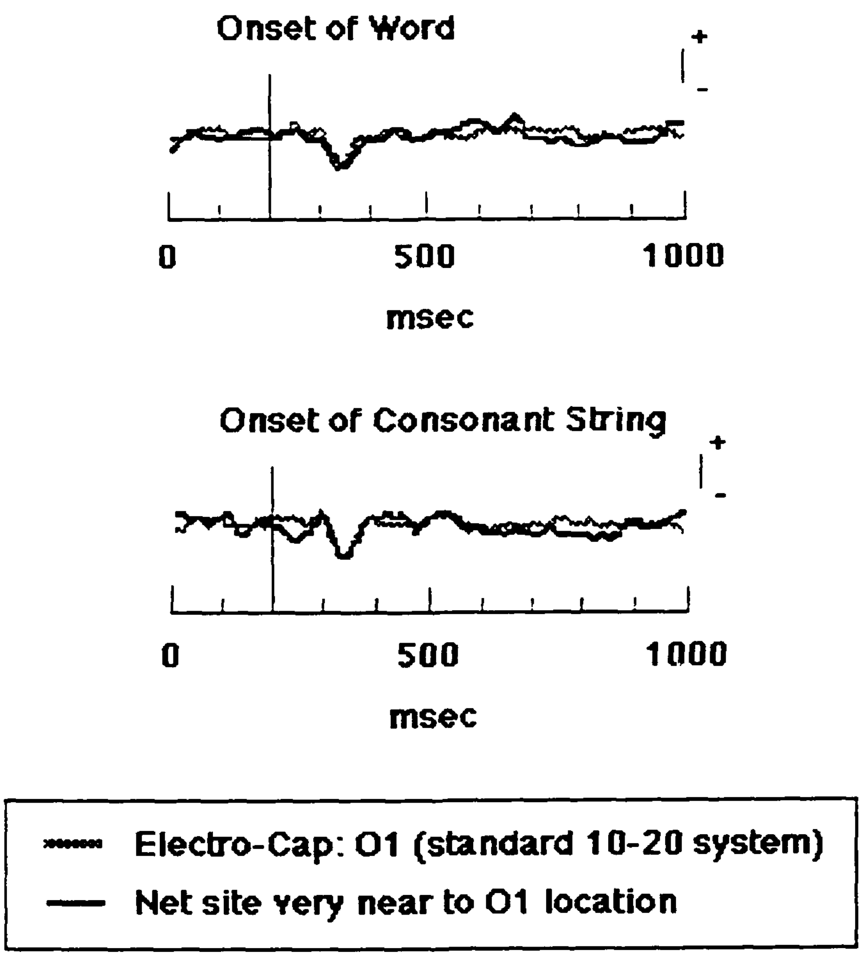
We have underway studies comparing 32 and 64 electrode systems as described in the first section of this report.. As part of this effort, we have begun to compare the standard electrocap system with the new Net system described in the first section. Several aspects of this procedure differ from the Electrocap methodology. Electrocap use requires blunt needle abrasion of the scalp at each electrode site, and perceptible pressure is maintained at all sites by anchoring the cap to a chest strap. The abrasion appears to intimidate and/or cause pain to only a small portion of subjects. However, the constant pressure of the cap becomes uncomfortable for most subjects within an hour. In contrast, subjects generally report comfortable fit (no pain) during the ninety minute span extending from application to removal of the Net in the Attention Level experiment. Positioning the Net lightly on the subject's head takes less time than electrocap positioning, and requires no chest strap. Once the electrodes have been placed on the subject's head, the time required for application per electrode is about 15 seconds, whereas the electrocap methodology requires several times that. After removal, the electrocap requires careful cleansing of each electrode, whereas the Net is simply replaced into a sterilizing electrolytic solution.; Whereas unusually shaped heads may occasionally yield floating electrodes due to cap wrinkles, this is less of a problem for the Net. For studies using mastoid references, these (and all other) sites are accessible after Net application, an improvement over the old cap.

Single Subject ERP Data

Passive Perception Task

Left Occipital Electrode Site

Electro-Cap Compared with Net



As tradeoff for the improvements listed above, certain new concerns accompany use of the Net. Hair that is thick and dry seems especially able to wick electrolytic liquid from sponges, which then require additional liquid to achieve adequate saturation for conducting electricity. During application, previously seated electrode tubes are susceptible to displacement during subsequent alignment of other tubes, though this does not seem to occur very often. During data collection, head movement produces a large data artifact presumably caused by sponge movement due to physical sway of electrode tubes. However, only a small percentage of such artifacts were produced by normal volunteer subjects in our pilot study.

References

Corbetta, M., Miezin, F., Dobmeyer, S., Shulman, G.L., & Petersen, S. (1990). Selective attention modulates neural processing of shape, color, and velocity in humans. In press: *Science*

Gibson, E.J., Shurcliff, A. & Yonas, A. (1970). Utilization of spelling patterns by deaf and hearing subjects. In H. Levin & J.P. Williams (Eds.) *Basic Studies of Reading. New York: Basic Books*

McClelland, J.L., & Rumelhart, D.E. (1986). Parallel distributed processing. *Cambridge: MIT Press*, Vol. 2l.

Snyder, A.Z., Petersen, S., Fox, P., & Raichle, M.E. (1989) ET studies of visual word recognition. J. Cerebral blood flow and metabolism. S576 (abstract).

Treisman, A., & Gormican, S. (1988). Feature analysis in early vision: Evidence from search asymmetries. *Psychological Review*, 95, 15-48.

Papers in Preparation for Publication

Carr, T., & Posner, M.I. Anatomical contributions to the acquisition of literacy. Paper to be presented to conference on literacy in Lake Como, Italy, March 1991 (to be published in proceedings).

Compton, P. Grossenbacher, P., Posner, M.I., Tucker, D., & Wiel, D. Attention to components of visual forms.

Compton, P., Grossenbacher, P., Posner, M.I., & Tucker, D. ERP studies of processing visual words and control strings. To be submitted to *Cognitive Neuroscience*.

Posner, M.I. Cognitive neuroscience of lexical access. Delivered to the 4th Yakult International Symposium, Tokyo, Japan, May 1990. (To be published in proceedings).

Posner, M.I. Mechanisms of attention. Paper to be presented to Decade of the Brain Conference in Washington D.C., 1990 (to be published in proceedings).

Posner, M.I., & Carr, T. A cognitive anatomical analysis of lexical access. Invited paper, *American Journal of Psychology* (to be submitted summer 1990).

Presentations

Compton, P., Grossenbacher, P., Posner, M.I., Tucker, D., & Wiel, D. A cognitive-anatomical approach to visual word form activation. Psychonomics Society, November 1990, New Orleans.

Posner, M.I. Computing the visual word form: a cognitive anatomical analysis. Paper presented to the symposium on Cognitive Neuroscience at the Cognitive Science Meeting in Boston, July, 1990.

Posner, M.I. Mechanisms of attention. Paper to be presented to Decade of the Brain Conference in Washington D.C., 1990 (to be published in proceedings).

Posner, M.I., & Compton, P. Computational energetic interactions in the left ventral occipital lobe. Invited paper to EPIC 7. The Netherlands, July 1989.